Building A Cryogenic Inchworm[â] Motor Technical Challenges and Proposed Solutions

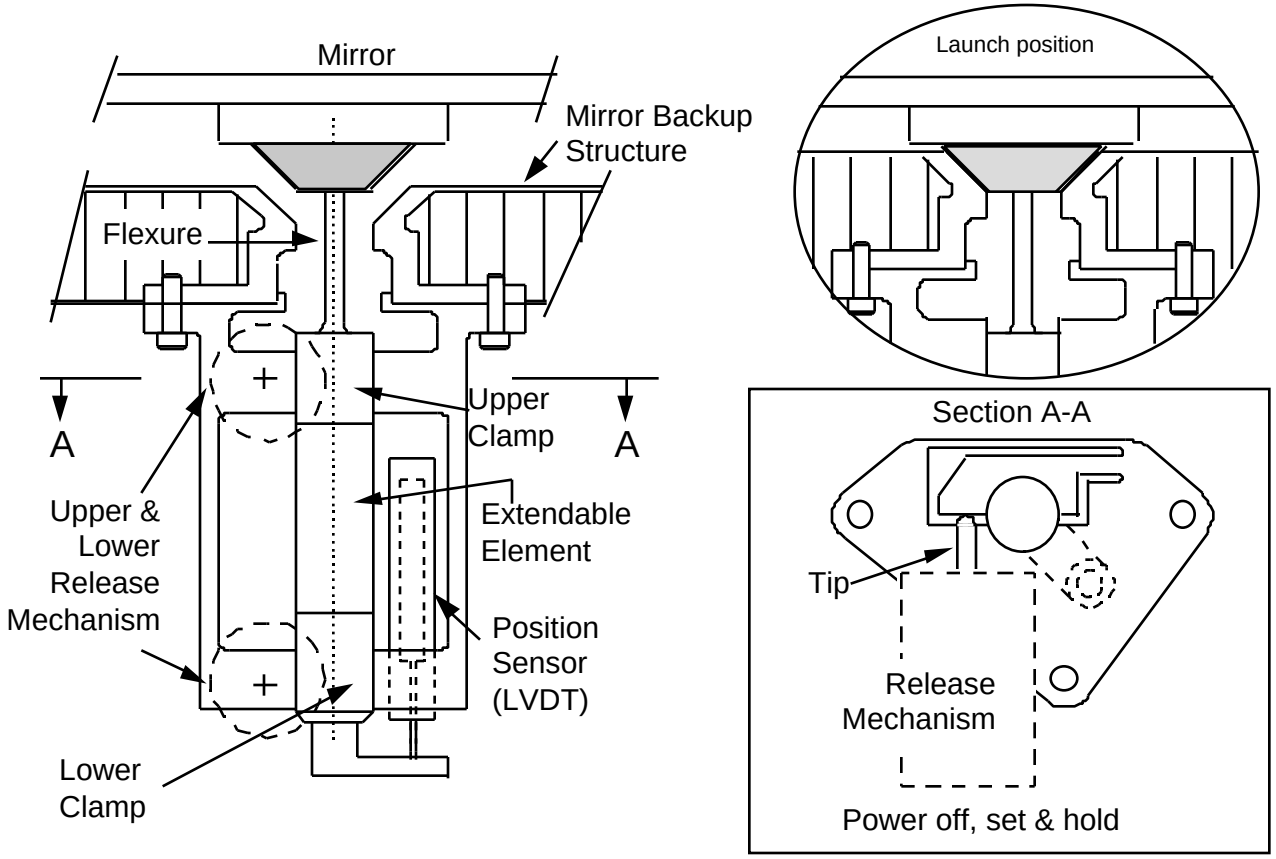
David Henderson
Director Of Positioning Products
Burleigh Instruments
Burleigh Park
Fishers, NY 14453

NGST Annual Technology Challenge Review #1
NASA/ Goddard Space Flight Center
Greenbelt, Maryland
July 8, 1997

[â] Inchworm is a registered trademark of Burleigh Instruments

Preliminary NGST Actuator Requirements
(From TRW Study 1996)

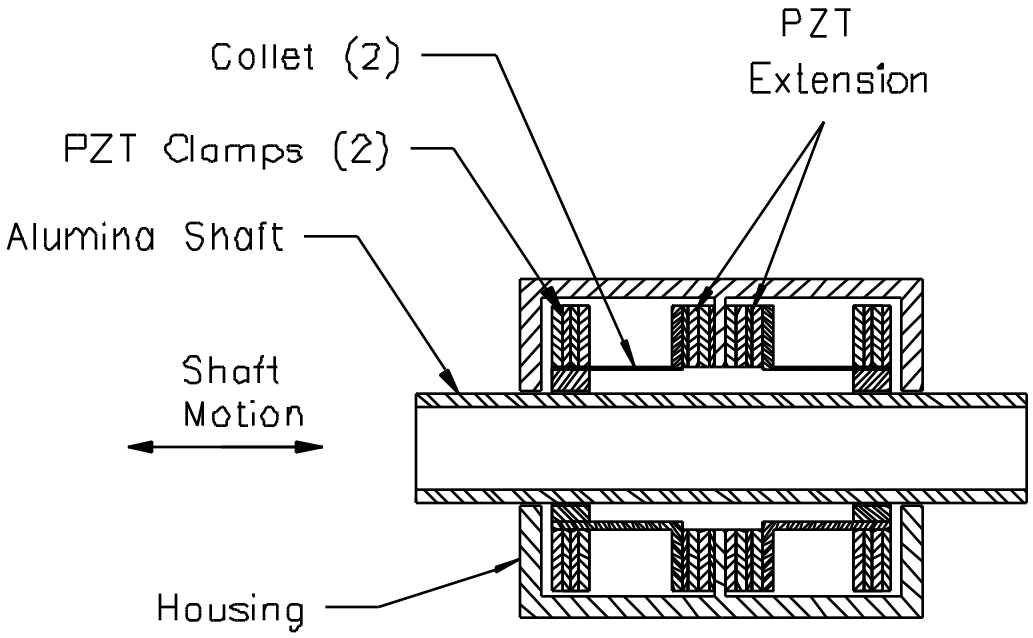
Inchworm Actuator with Launch Lock Mechanism



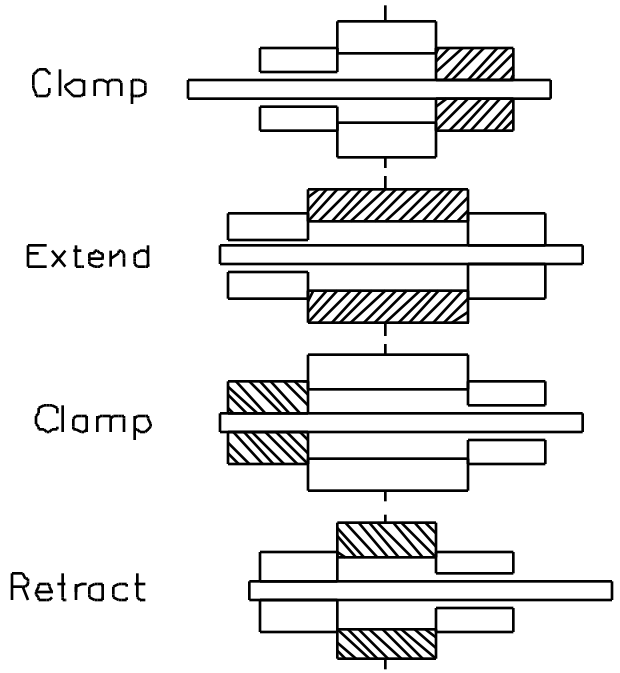
Preliminary NGST Actuator Requirements

- Range of 6 millimeters
- Resolution of 10 nanometers
- Push Force of 25 Newton's
- **Hold position with power-off to allow for multiplexing of drive electronics**
- **Space qualified for operation at 30 °K**
- Low power consumption, simple, reliable and cost effective
- 240 to 3000 actuators required depending on the final design

Traditional Inchworm Motor (1974)



Traditional Inchworm Design



Operating Sequence

Inchworm Advantages

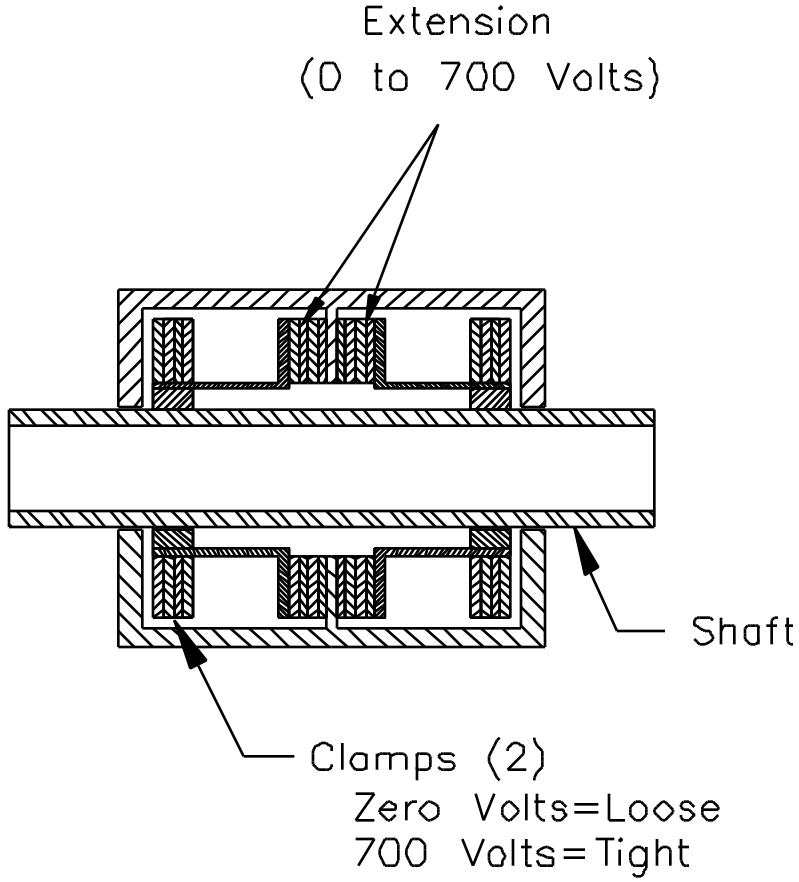
- One nanometer resolution while providing hundreds of millimeters of travel.
- Push forces greater than 15 Newton's (Typically > 30 Newtons)
- Speeds greater than 2 mm per second.
- **Solid state construction produces zero backlash, high stiffness and stability.**
- **Ultra High Vacuum compatible.**
- Non-magnetic materials.
- **Zero power dissipation when holding position.**
- Manufactured for more than twenty years.

Inchworm Limitations For The NGST

The off-power position of the motor is not stable because:

1. The clamps are honed to fit the shaft with a small interference fit at off-power (zero volts). This fit changes with temperature and wear which changes the off-power holding force. (Typically it is reduced to near zero over the life of the motor.)

2. When power is removed the extension stack changes length which can change the shaft position a few micrometers.

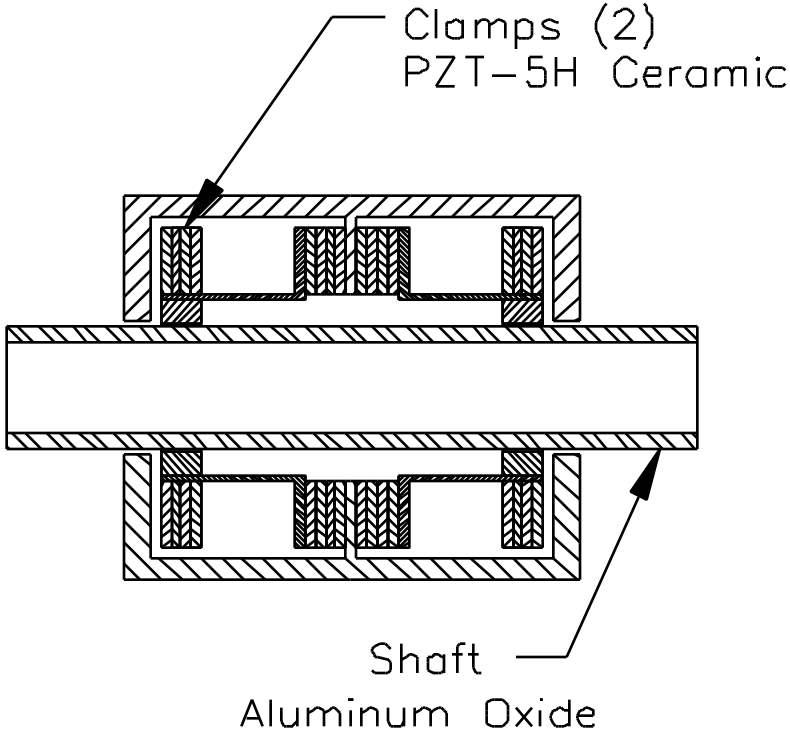


Inchworm Limitations For The NGST

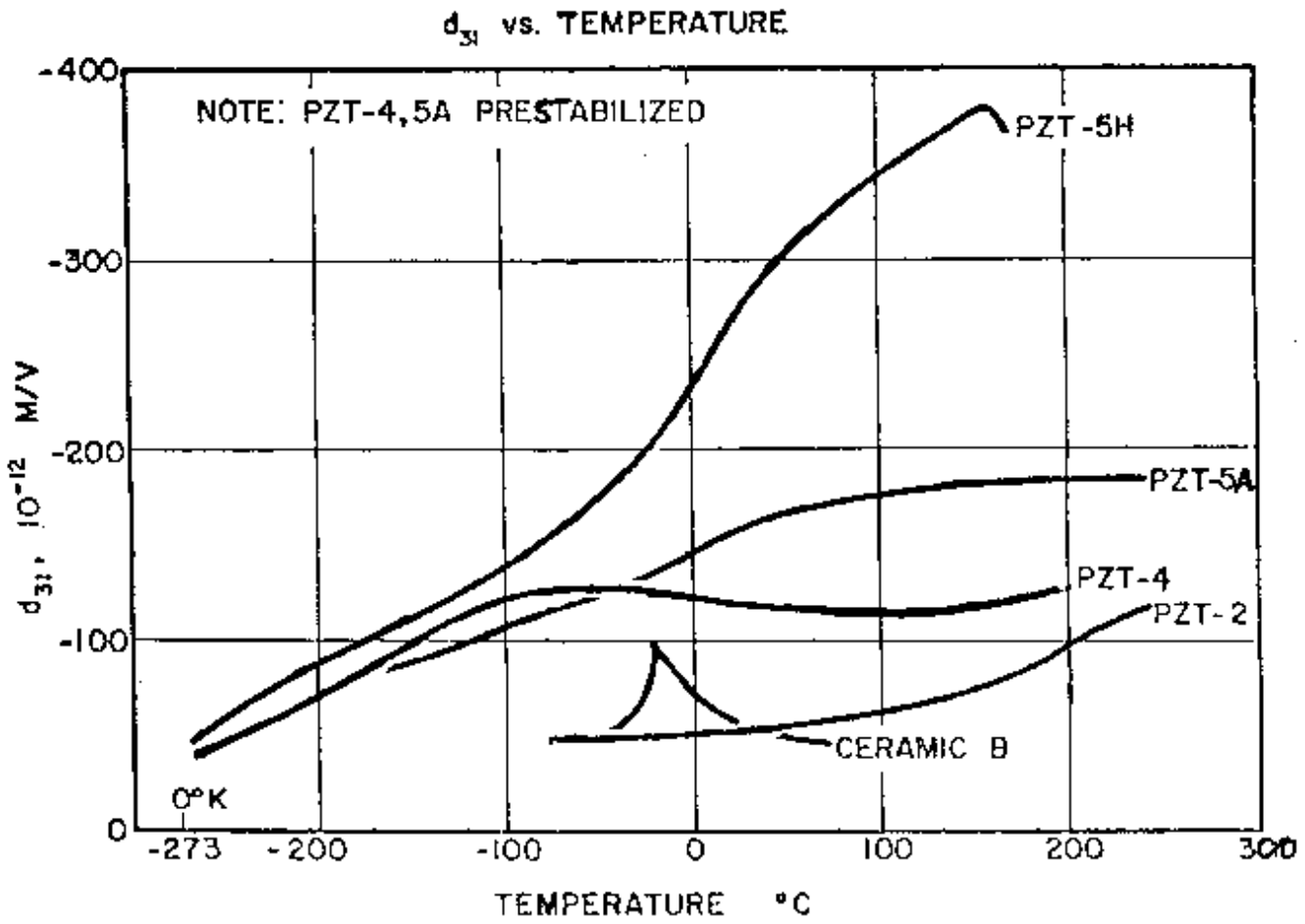
The operating temperature range is limited to zero to 70 degrees C. because:

1. The clamp and shaft materials have different thermal expansion coefficients. At lower temperatures the shaft-clamp fit gets tighter and will break the PZT ceramic. At higher temperatures the shaft-motor fit gets looser and the motor will stop operating. Eventually the curie temperature of the PZT is exceeded.

2. PZT-5H looses 80% of its strain at 30 °K. (See next slide.)



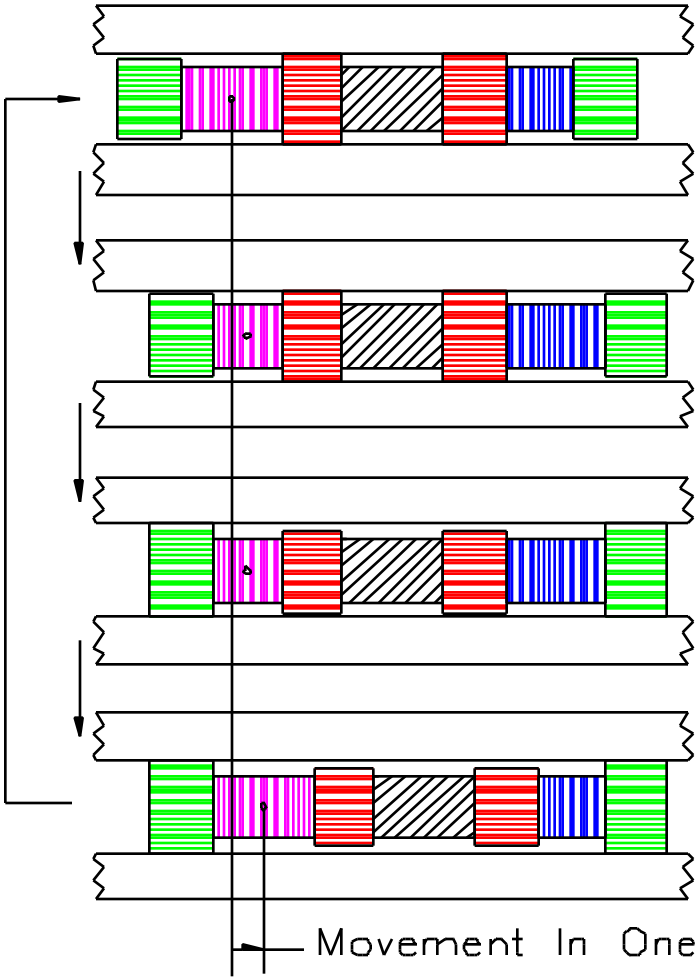
The Temperature Sensitivity Of Current PZT Materials



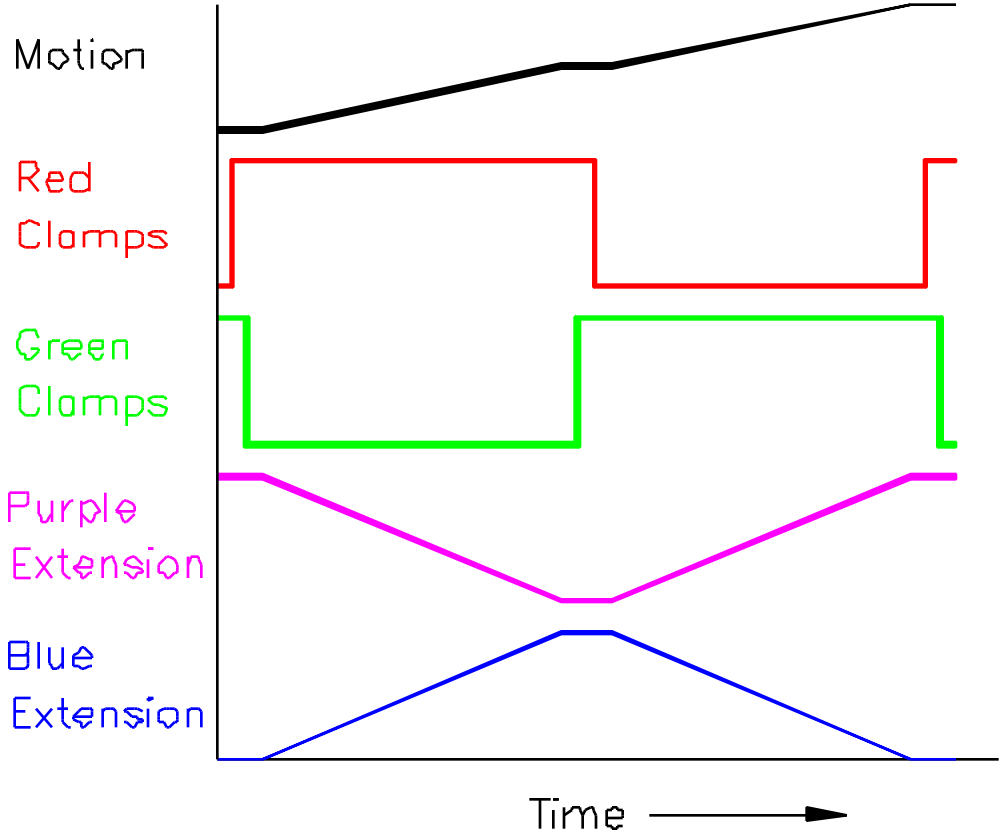
Temperature Versus Strain/Voltage Sensitivity For Various PZT Materials
(From Morgon Matroc's Published Data)

Demonstrated Inchworm II Design

(Patent Pending)



Motion Sequence

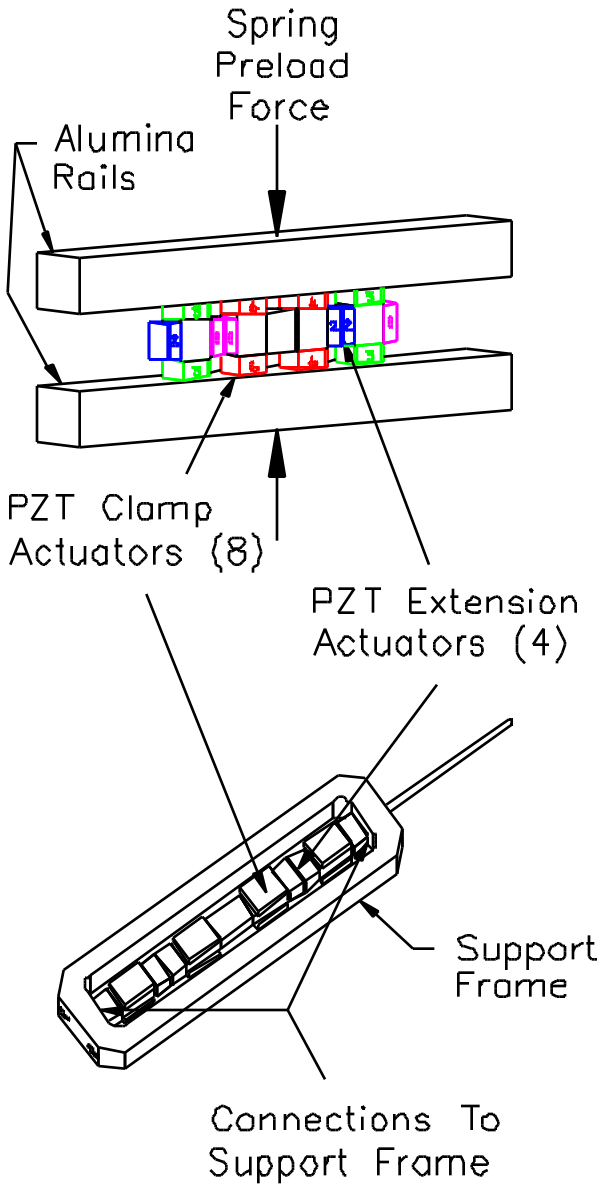


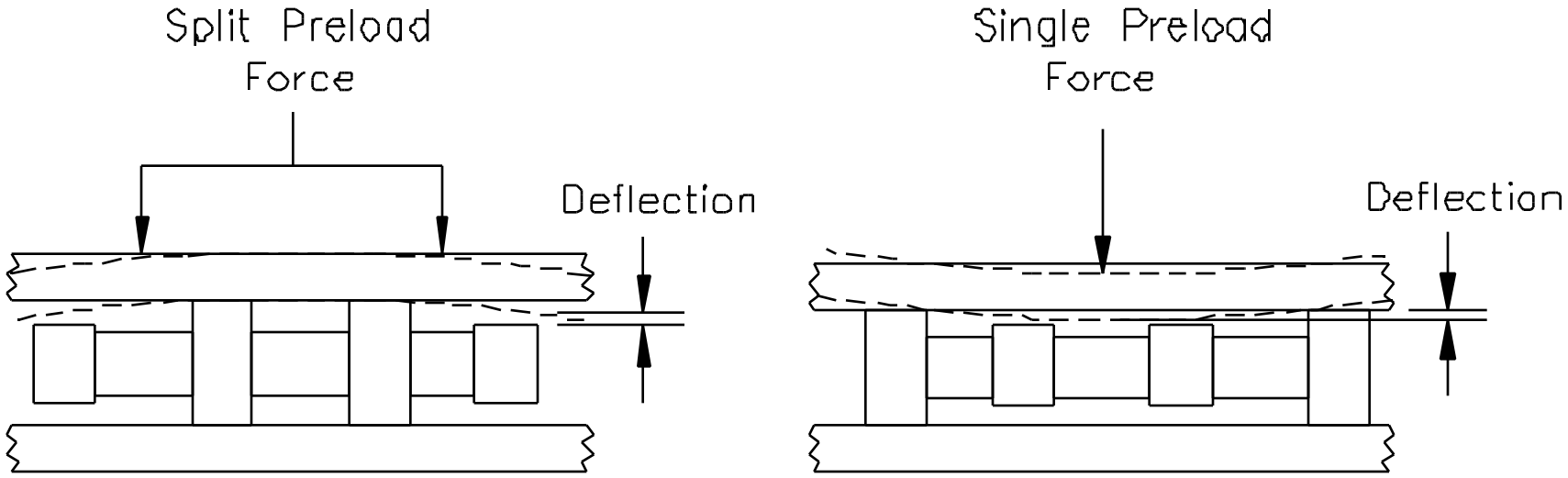
Drive Signals

Demonstrated Inchworm II Improvements (Patent Pending)

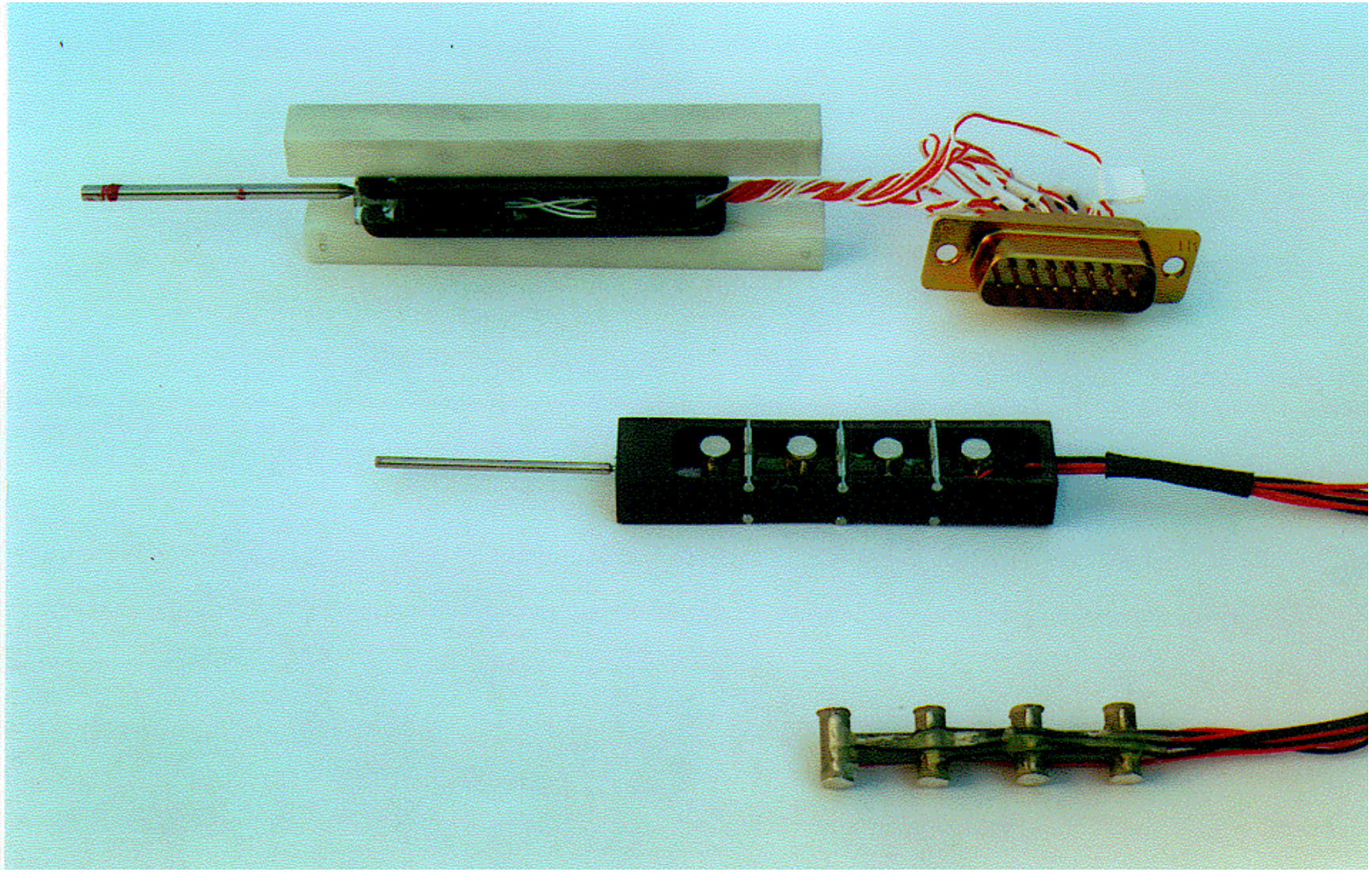
- Tensile stresses are eliminated using "inside out" PZT clamps.
- Precision interference fit is replaced by spring loaded rails and pads. (Only flat and co-planar surfaces are required.)
- **Spring loading compensates for wear and temperature changes.**
- Push force is proportional to preload.
- **Stable off-power holding force is achieved.**
- Lower voltage co-fired multilayer PZT actuators are used.

Limitations On Preload: Rail Deflection

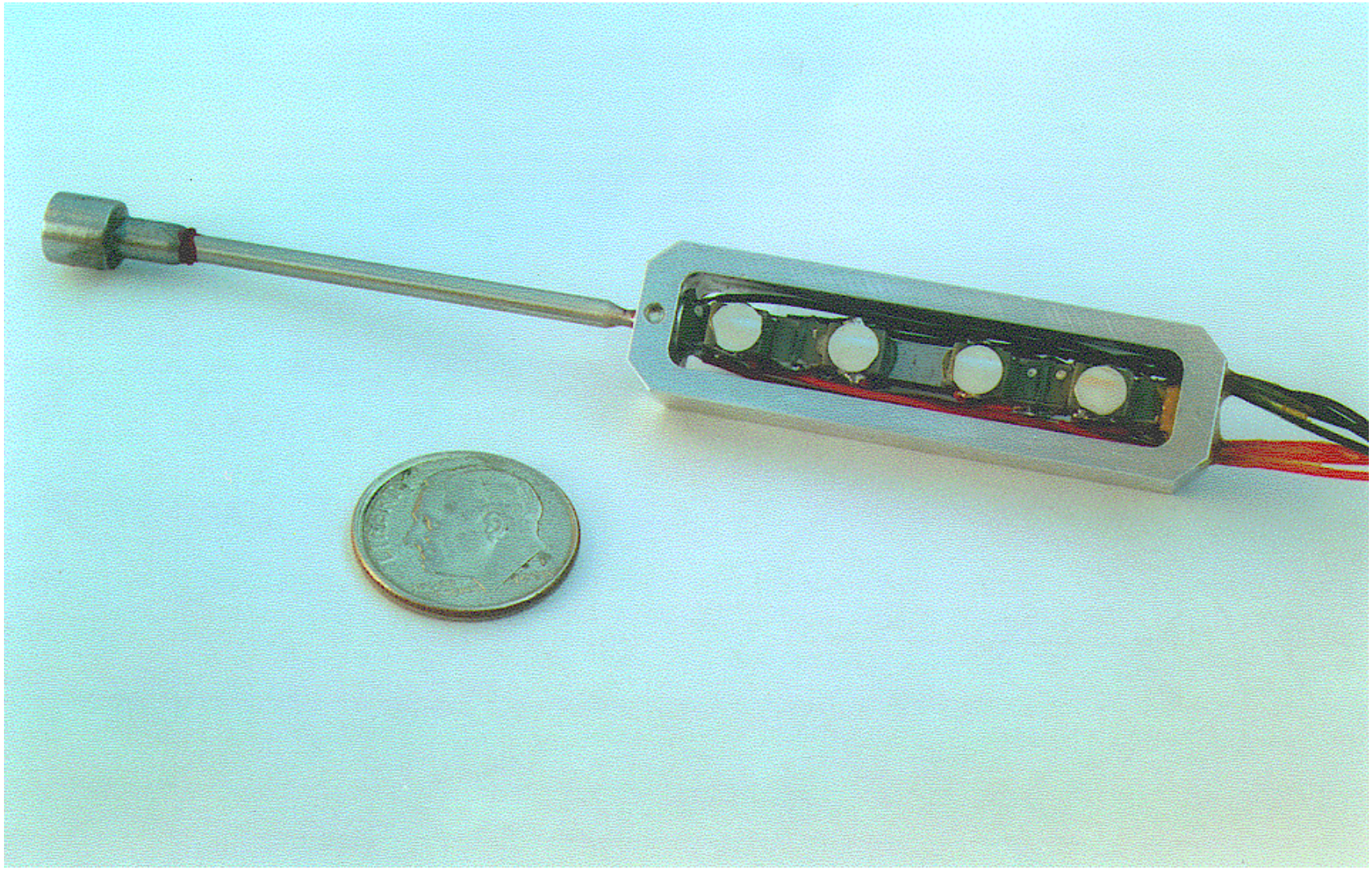




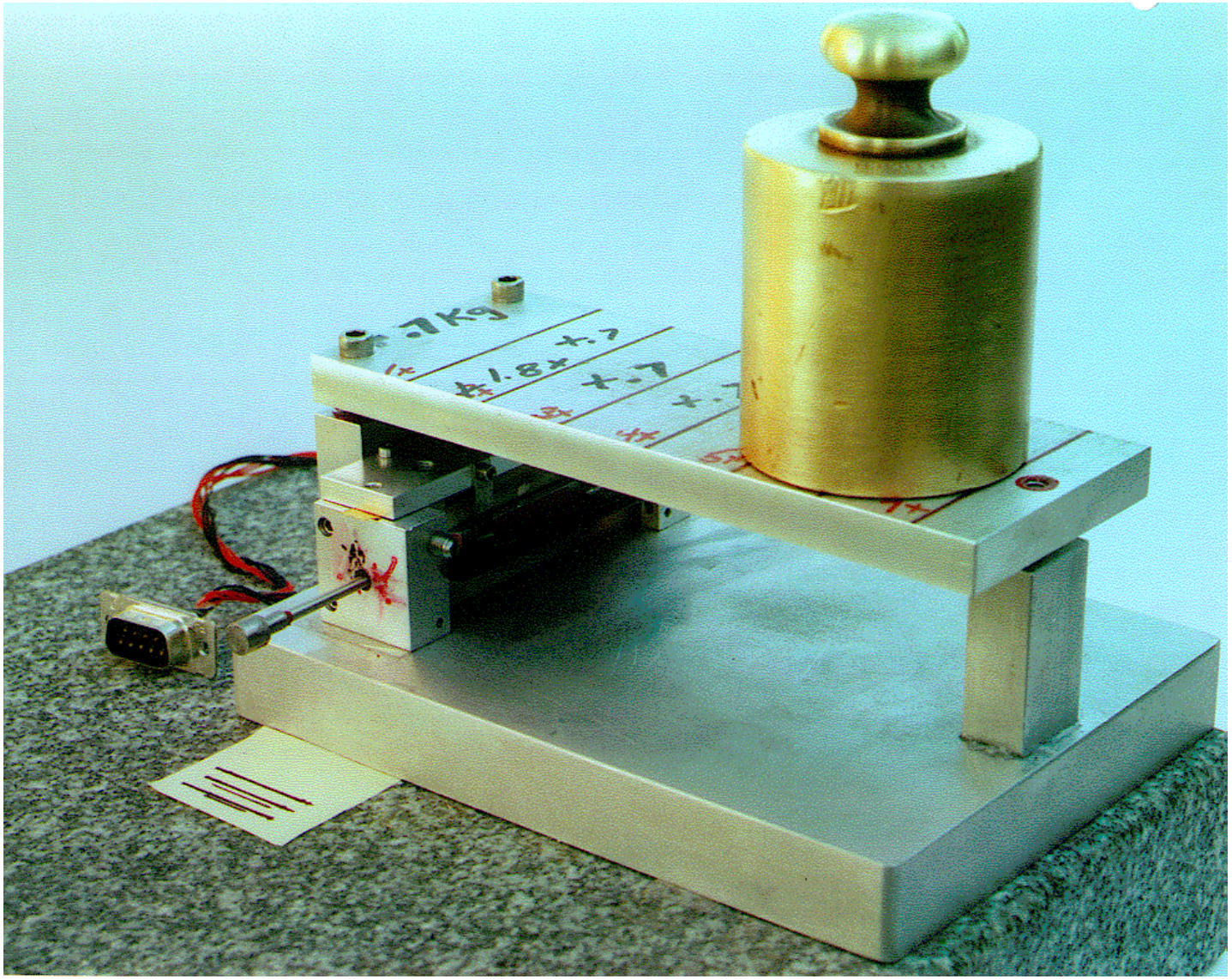
Design criteria for rail deflection is a maximum of one to two micrometers based on using rails and clamping surfaces that are flat and co-planer within 0.25 micrometers.



Early Prototype Inchworm II Motors



Final Prototype Inchworm II



Final Prototype In Test Fixture

Inchworm II For The NGST

We have demonstrated a version of the Inchworm II that uses spring loading to:

- Compensate for dimensional changes at 30 °K.
- Produce a stable off-power holding force.

Other Inchworm II Performance Results

- Nanometer resolution with millimeters of travel.
- Push force greater than 40 Newton's.
- Speed greater than 1 mm/second.
- Approximately 50 nm glitch.

Note: This Inchworm II development was completed under NASA/JPL Phase II SBIR contract (NAS7-1300) "Active Truss Strut" in partnership with Intelligent Automation Inc. 2 Research Place, Suite 202, Rockville, MD 20850.

How to deal with reduced PZT strain at 30 °K?

Option 1:

Use new active materials currently under development by TRS or others.

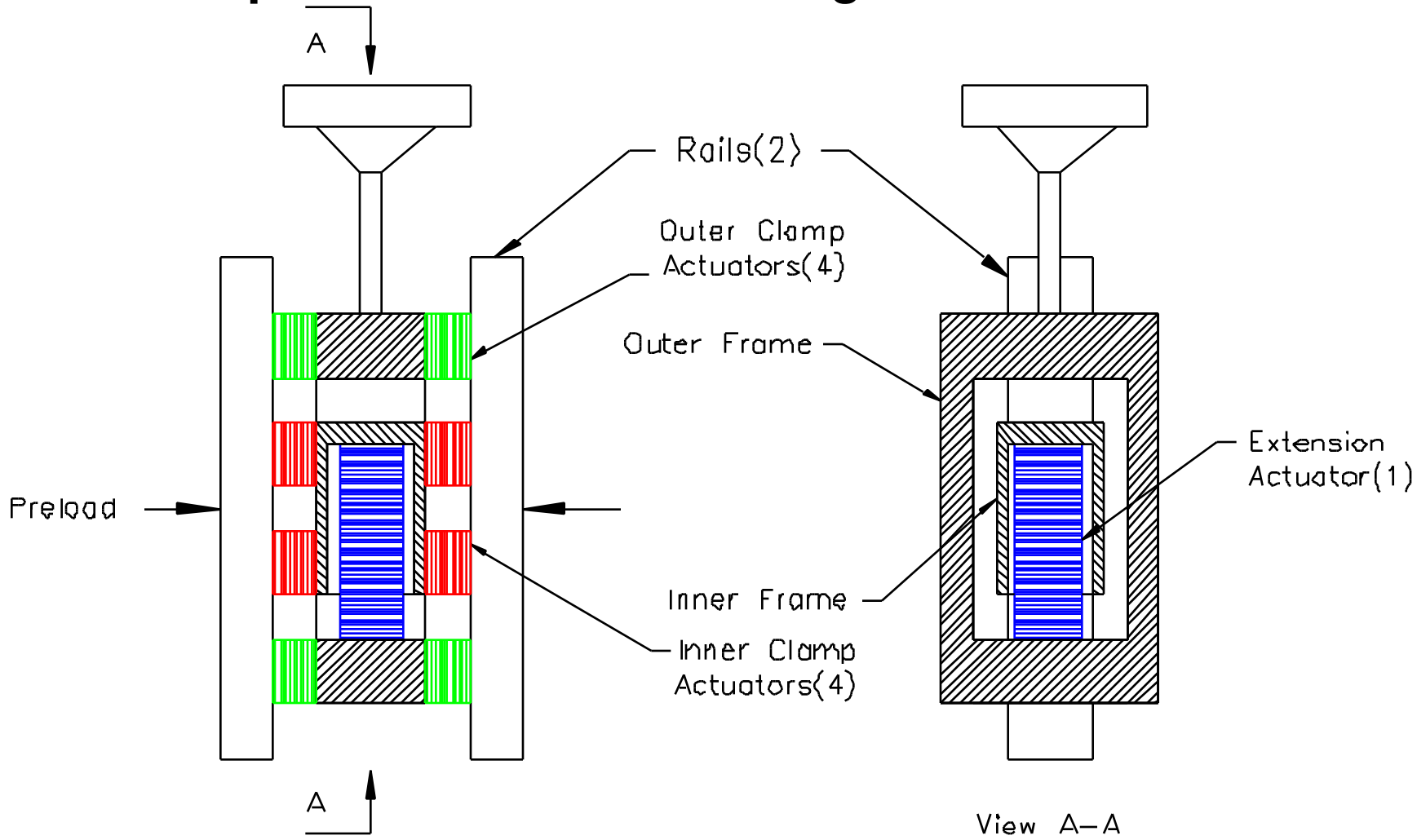
Note:

Testing at ambient temperatures must still be completed using traditional PZT materials.

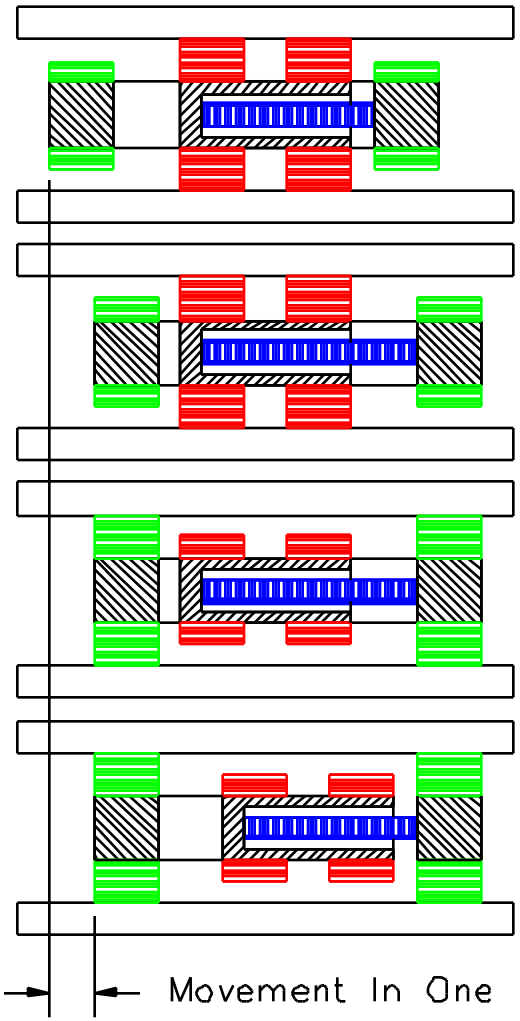
Option 2:

Design the Inchworm with “extra” traditional PZT material in the clamps and extension sections so that sufficient strain is available for operation at cryogenic temperatures. Calibrate the motor and control system for operation at both temperature extremes.

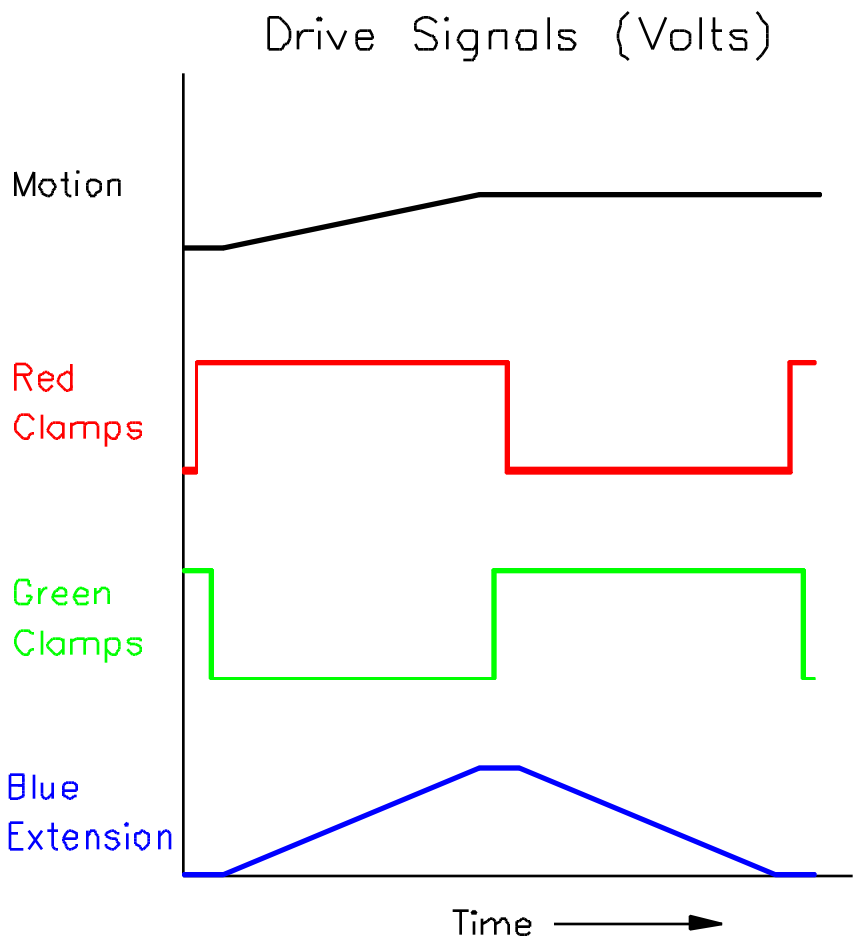
Proposed Inchworm II Design For The NGST



Proposed Inchworm II Design For The NGST



Motion Sequence



Drive Signals (Only Three Channels Instead of Four)

Power-Off/Power-On Sequence That Does Not Change Position

(Necessary To Multiplex One Controller With Many Motors)

Power-Off

1. Maximum volts to all clamps.
2. Zero volts on inner clamps (red).
3. Zero volts on extension (blue).
4. Zero volts on outer clamps (green).
5. Switch to another Inchworm.

Power-On

1. Maximum volts to outer clamps (green).
2. Zero volts to inner clamps (red).
3. Midpoint volts to extension (blue).
4. Maximum volts to inner clamps (red).
5. Zero volts to outer clamps (green).
6. Make position adjustment using extension (blue).

Summary

- The “inside-out” clamp design of the Inchworm II offers all the traditional Inchworm advantages plus:
    - Stable off-power holding force and position
    - Operation at 30 °K
- The Inchworm II design can easily incorporate:
    - New cryogenic active materials currently under development

OR

    - Extra standard PZT material so that sufficient strain is available to operate at 30 °K